Closed-Circuit Wind Tunnel Design for Lunar Dust Filtration Tests

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[Abstract] A closed circuit wind tunnel is being designed to test different high efficiency particle aerosol (HEPA) filters and other filtration concepts against lunar dust loadings. ASHRAE and Lawrence Livermore National Laboratory Standards were used to establish regulations for future filtration tests.

I. Introduction/Background

NASA's vision is to eventually establish human outpost stations on the moon. As a result, scientists need to test different air circulation and filtration systems to make such efforts possible. The additional loading of lunar dust will challenge future exploration filtration systems and poses a biological hazard to astronauts. Lunar dust is very different from that on Earth in the sense that it is abrasive and ultra fine. If it gets into the living quarters of the astronauts it poses a threat to their lungs and can also damage sensitive equipment. The scope of this project is to build a closed circuit wind tunnel (CCWT) to test different high efficiency particulate air (HEPA) filters and different filtration concepts. The closed circuit configuration allows experimenters to control inner duct conditions and ultimately reducing the pressure to model environments on the moon.

II. Standards and Regulations

In order to properly conduct filtration experiments, there are standards that we needed to follow. As a result, we purchased two standards, the American Society of Heating Refrigeration and Air-Conditioning Engineers Standard 52.2 and the Lawrence Livermore National Lab Standard on HEPA filtration. From both of these regulations we extracted critical information on proper sampling, leakage test, and flow characterization. From these subject areas we were able to establish our own regulations that will be followed when finalizing the design of the wind tunnel and conducting experiments.

A. ASHRAE 52.2

The ASHRAE 52.2 Standard gave significant insight on proper sampling techniques and equipment. The standard 4.42 states, "The portion of the sampling line in the duct area shall block less than 10% of the duct cross sectional area." Since there are numerous probes and inducers that are needed in the test area, this standard was taken into account when placing probes near the filter in the test section. Because of their size and shape, the mere presence of the probes will create turbulence. However, if they do not occupy more than 10% of the cross sectional as mentioned in the standard they will not disrupt the particles entering the filter

B. Lawrence Livermore National Laboratory HEPA Filter and In-Place Leak Testing Standard

The second standard, the Lawrence Livermore National Lab Standards, focused on HEPA filtration test and gave insight on how to control aerosol uniformity based on wind tunnel dimensions. Regulation 5.2.1 states that, “Adequate duct length is required to allow the air velocity and the aerosol concentration to become uniformly distributed. This is ensured by placing the downstream sampling location >7.5 duct diameters from closest source of turbulence.” As a result, the overall size of the wind tunnel was designed so there is enough room for complete dispersion of the lunar dust particles, especially downstream of the honeycomb and upstream of the test filter. If the wind tunnel is scaled up at a later date, the ratio of the inner width of the duct and the length of the test section must remain constant.

In addition to the dimension ratios that were provided in the Lawrence Livermore Standard, it discussed the proper method of how to quantify and assess leaks within the duct. Since, controlling the pressure within the duct is the main motivator behind the closed circuit configuration, controlling leaks are a high priority. Standard 6.1 states, “HEPA filters are acceptable if the percent leakage is equal or less than 0.03**%** or the value is less than 0.05%. If the in-place leakage exceeds 0.03% and cannot be adjusted by correcting the sealing clamps, the HEPA filter shall promptly be replaced.” These percent values are in reference to leaks around the three filters. As a result, there will be additional sealing and gaskets surrounding the filter and wind tunnel. Since there filters are variable in size, there is an adjustable section is being developed to account for misalignment that may occur when testing different filters.

III. Wind Tunnel sections

The wind tunnel will be made of nonstatic plexi glass. The tunnel in its entirety is comprised of five different compartments and sections. These include the test section, two nozzles, four straight sections, two bend sections, and an axial fan compartment. In addition there are a total of three filters, the primary HEPA test filter and two other supporting filters. These two supporting filters ensure that particles that pass through the test filter do not reach the axial fan and as a result eliminating excess dust circulation back into the test area.

The overall dimension of the tunnel is 7 x 2-½ ft with an inner square cross section of 8 ¾” x 8 ¾”. Since seals and leakage is a significant concern, every section is equipped with flanges and gaskets.

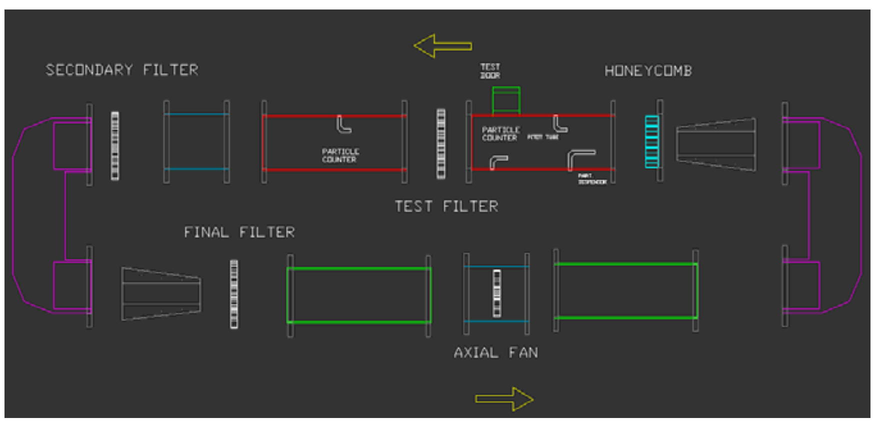

Figure 1. Entire wind tunnel layout design.
This blueprint shows the location of the three filters relative to the fan and particle source.

The most significant section in the tunnel is the primary filter test section. The test section is made up of three sections, a honeycomb flow controller and two straight plexi glass compartments. The first section located upstream of the filter houses the particle dispenser, Pitot tube and first of two sampling probes that measures the amount of particles entering the filter. While the second section houses the second particle counter and Pitot tube that measures the pressure drop that is associated with HEPA filtration. Because of the two counters, experimenters will be able to determine the number and size of the particles entering the filter and those passing through, in essence indicating filter efficiency. Based on the ASHRAE 52.2 Standard the sampling probes cannot occupy more than 10% of the duct area. Experimenters will have to take into account the diameter of the sampling probe heads as well as proper tubing.

IV. Probes and Instrumentation

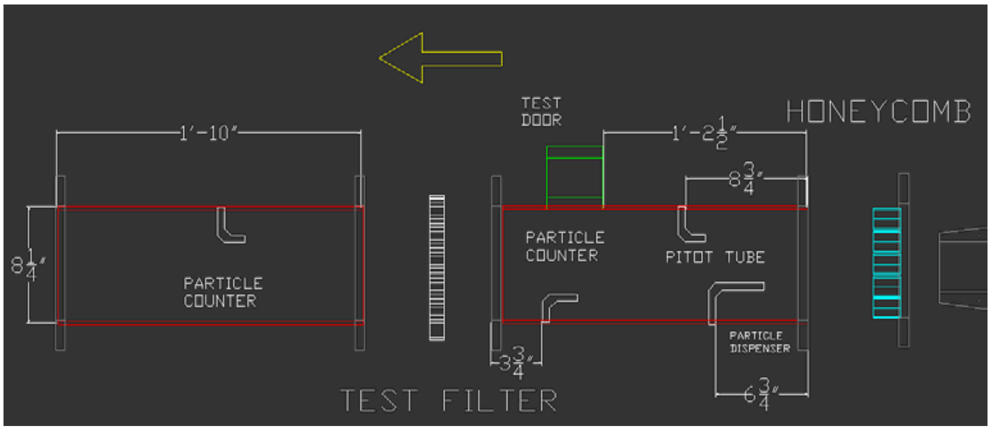

Figure 2. The test section and the layout of the particle detectors and flow sensors.

The wind tunnel that is being design will be interactive with computers and other instrumentation. There are two different types of probes that will be located inside the wind tunnel duct. These to probes include, particle detectors or sampling probes and flow sensors. All of the particle detectors are from TSI Inc. and are used to count and measure the size of the particles that are either entering the filter or have passed through. These detectors are very sensitive and can measure particles that range from 2.5 µm – 10 nm. As a result, they will be located outside of the duct. A separate sampling system will be set up within the test area and will be comprised of a sampling probe and tubing that will properly transfer particles from the wind tunnel to the particle detectors. Scientist would like to make sure that the samples they collect are a true representation of the environment within the wind tunnel. As a result, scientists want to ensure that the air stream entering the collector has a velocity equal to that of the air in the gas stream just ahead of the sampling port (1). This method of sampling is known as isokinetic sampling.

The second set of probes are the flow sensors, which monitor the airflow and pressure within the wind tunnel duct. A pressure inducer and Pitot tube will be located on the back end of the loop, where sampling and turbulence caused by probes is not as much of a concern. A Pitot tube has the ability to measure the dynamic and static pressure within the duct and are often used in HVAC applications. Based on these to values and Bernoulli's equation, experimenters can derive air velocity.

V. Conclusion and Future Work

As stated in the previous sections, his is an initial design project and as a result, there is still room for design and developments in order to test facility for HEPA filters against lunar dust particles. Based on the ASHRAE 52.2 and Lawrence Livermore Standards, future work will have to include purchasing needed probes, finalizing the design with engineers and actually building or purchasing wind tunnel sections. Even though the test section is actually built and is made of Plexiglas, design engineers will have to determine the material of the remaining sections especially on the two bend sections. Experimenters will have to meet with additional design engineers to determine if the wind tunnel will endure the pressure difference that is going to be lowered. Many wind tunnels have a circular cross section, however, for sealing reasons, we chose a square cross section. The wind tunnel will have to pass safety expectations before it can be built. Since it is known that the lunar dust particles present a biological hazard, there will have to be instructions and protocols written for experimenters who will be handling the particles during the actual test. These different instances when the experimenter comes in contact with the dust particles is when, experimenters are changing loaded filters, or cleaning the various sections. Also, instructions will need to be written for experimenters that will be loading the lunar dust into the dispenser tray. Since this is a prototype and initial design, it gives design engineers and lead scientist an idea of the layout and orientation of a closed circuit wind tunnel.

VI. References

1. IUPAC Compendium of Chemical Terminology, "isokinetic sampling (in atmospheric chemistry)," URL: http://iupac.org/goldbook/I03286.pdf [2nd Edition, 1997].

VII. Acknowledgments

I would like to thank PhD. Juan Agui for guidance and assistance on this project. Also, I would like to that Dr. David Kankam, Kamara Brown, and Michael Lamberty, and the entire NASA Academy staff for giving me the opportunity to come to Glenn and participate in the Academy. Finally I would like to thank Cheryl Dillard-Ewing at the Maryland Space Grant for the financial support.